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Spandl et al.

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(54) **LOW SPEED WIND TUNNEL DESIGN FOR AGRICULTURAL SPRAY PARTICLE ANALYSIS**

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(51) **Int. Cl.**

G01M 9/00	(2006.01)
G01M 9/04	(2006.01)
G01N 15/02	(2006.01)

(52) **U.S. Cl.**

CPC ***G01M 9/04*** (2013.01); ***G01N 15/02*** (2013.01); ***G01N 15/0205*** (2013.01)

(58) **Field of Classification Search**

None

See application file for complete search history.

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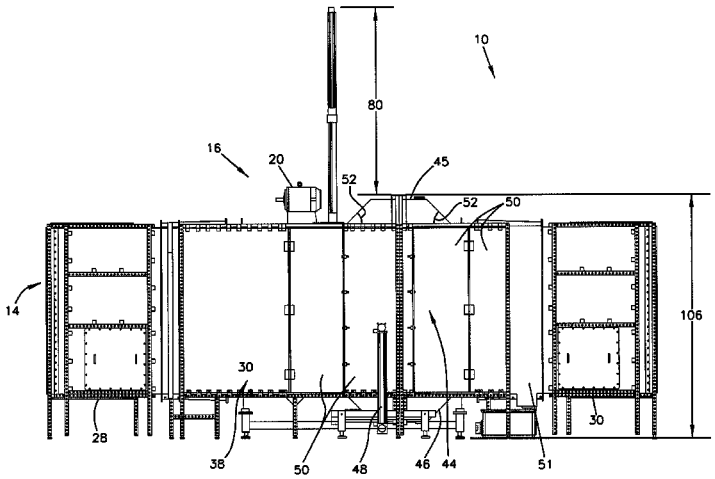
(57) **ABSTRACT**

A wind tunnel device defines a cyclical tunnel to receive continuous airflow. Airflow is delivered through the tunnel to a testing region that includes a first portion carrying an arm including a spray tip configured to spray particulates in the testing region at an angle, and a second portion including an enlarged cutout region configured to receive the angled sprayed particulates. As airflow carries the angled spray particulates into the second portion, the enlarged cutout region enables the spray particulates to pass through and exit the second portion of the testing region. Analysis in the second region may be conducted through transparent walls free of openings to minimize exposure of the spray particulates to the exterior of the device. A scrubber is adapted to extract spray mist from the airflow as the airflow exits the testing region and is re-circulated through the cyclical tunnel.

22 Claims, 7 Drawing Sheets



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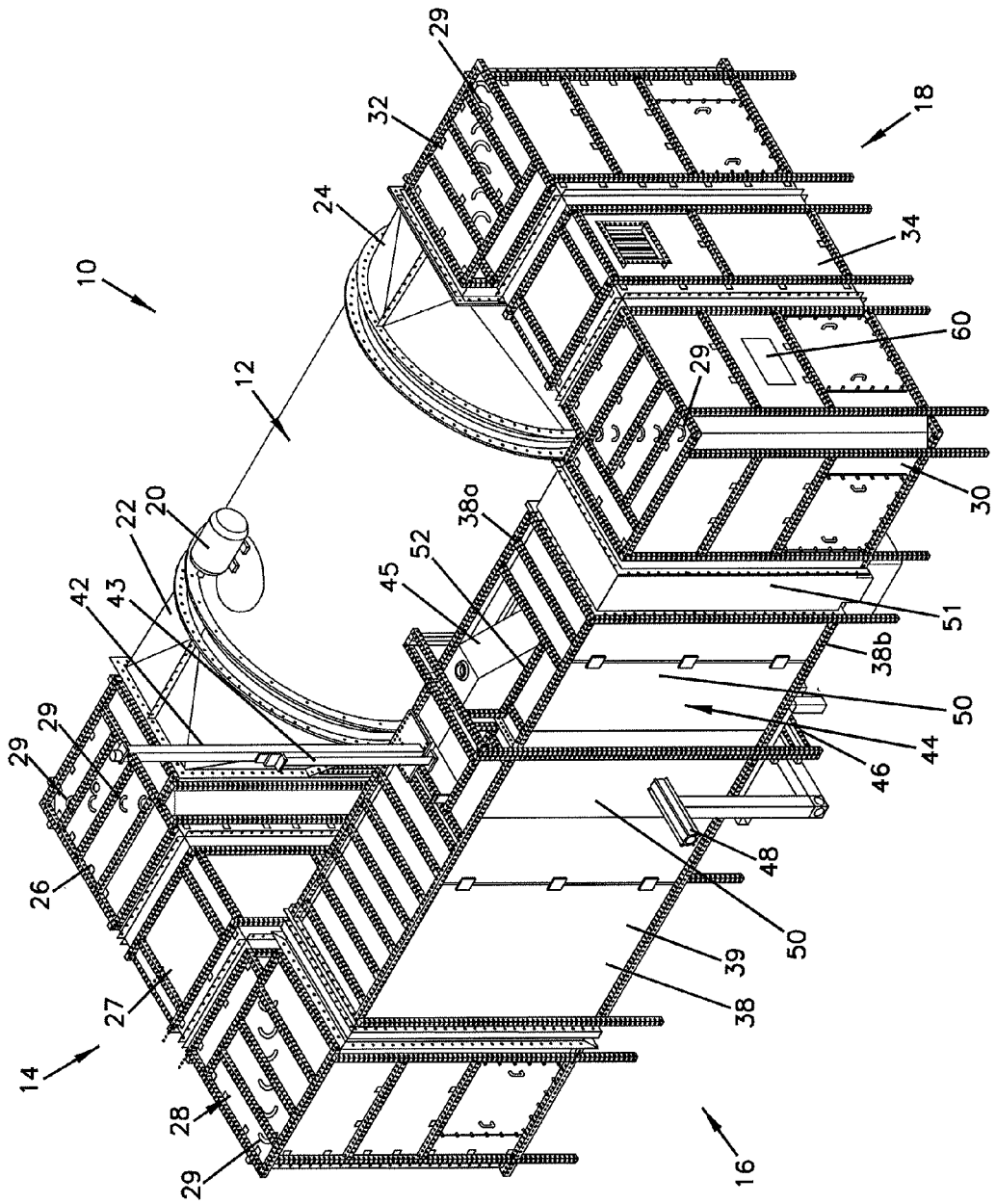
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FIG. 1

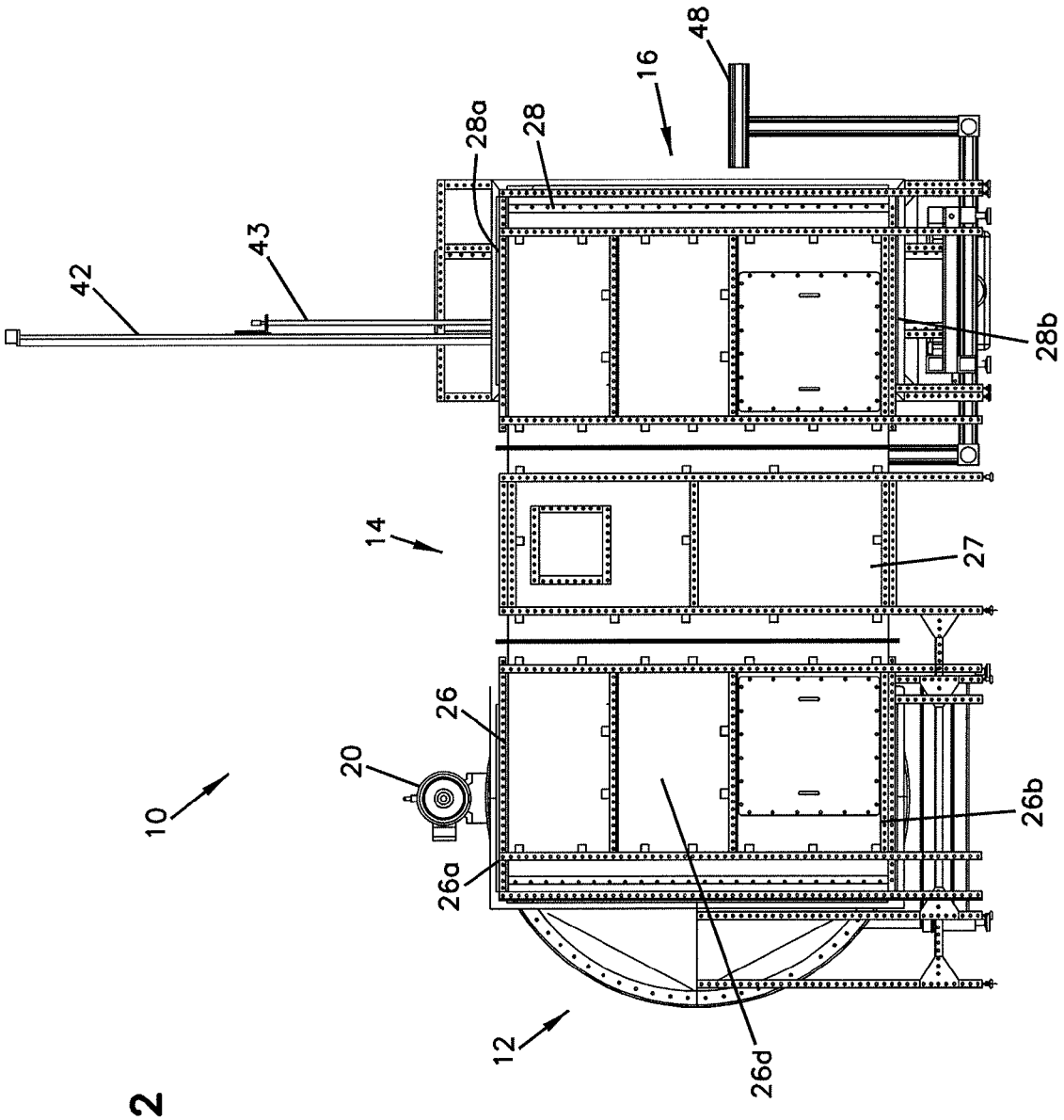

FIG. 2

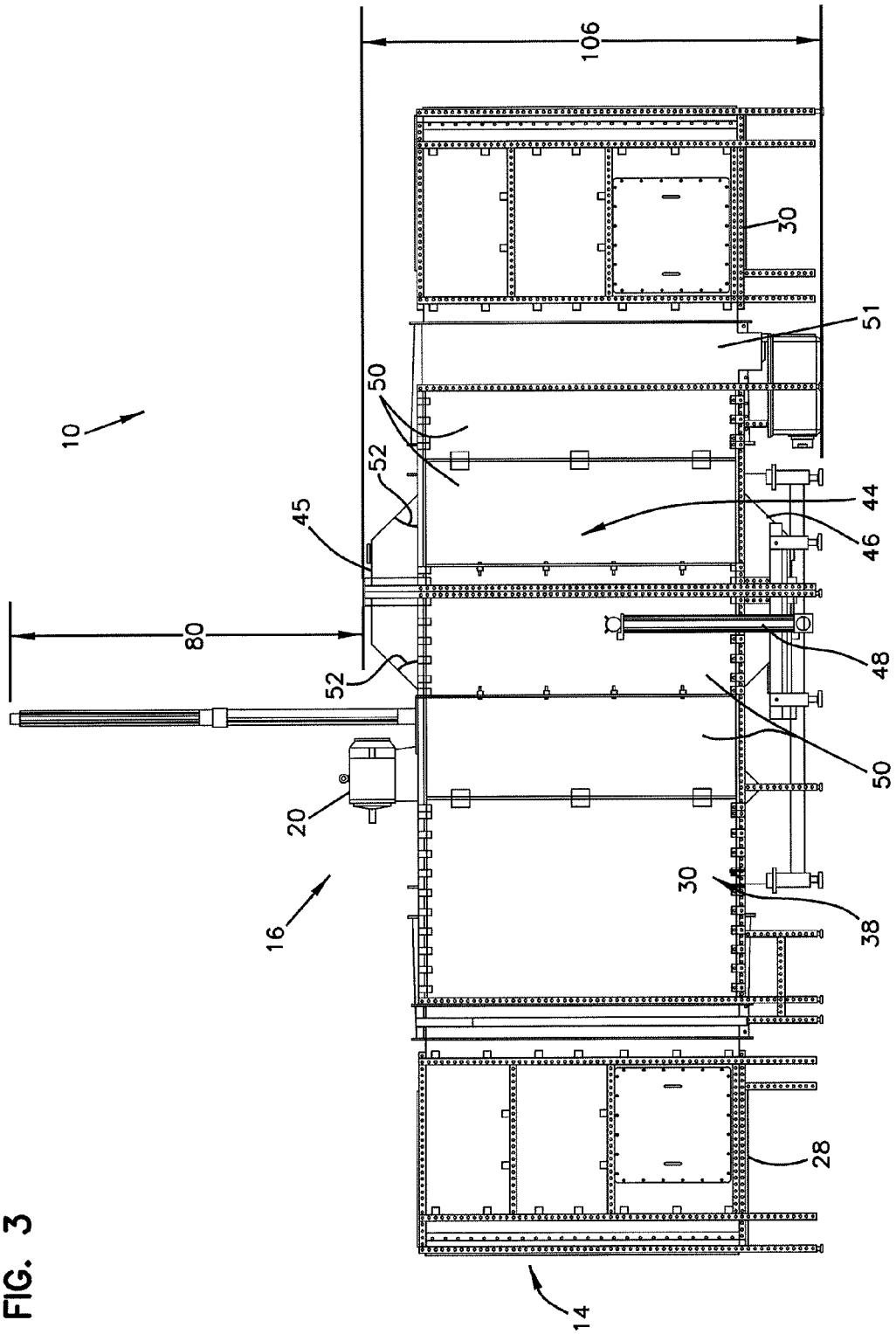

FIG. 3

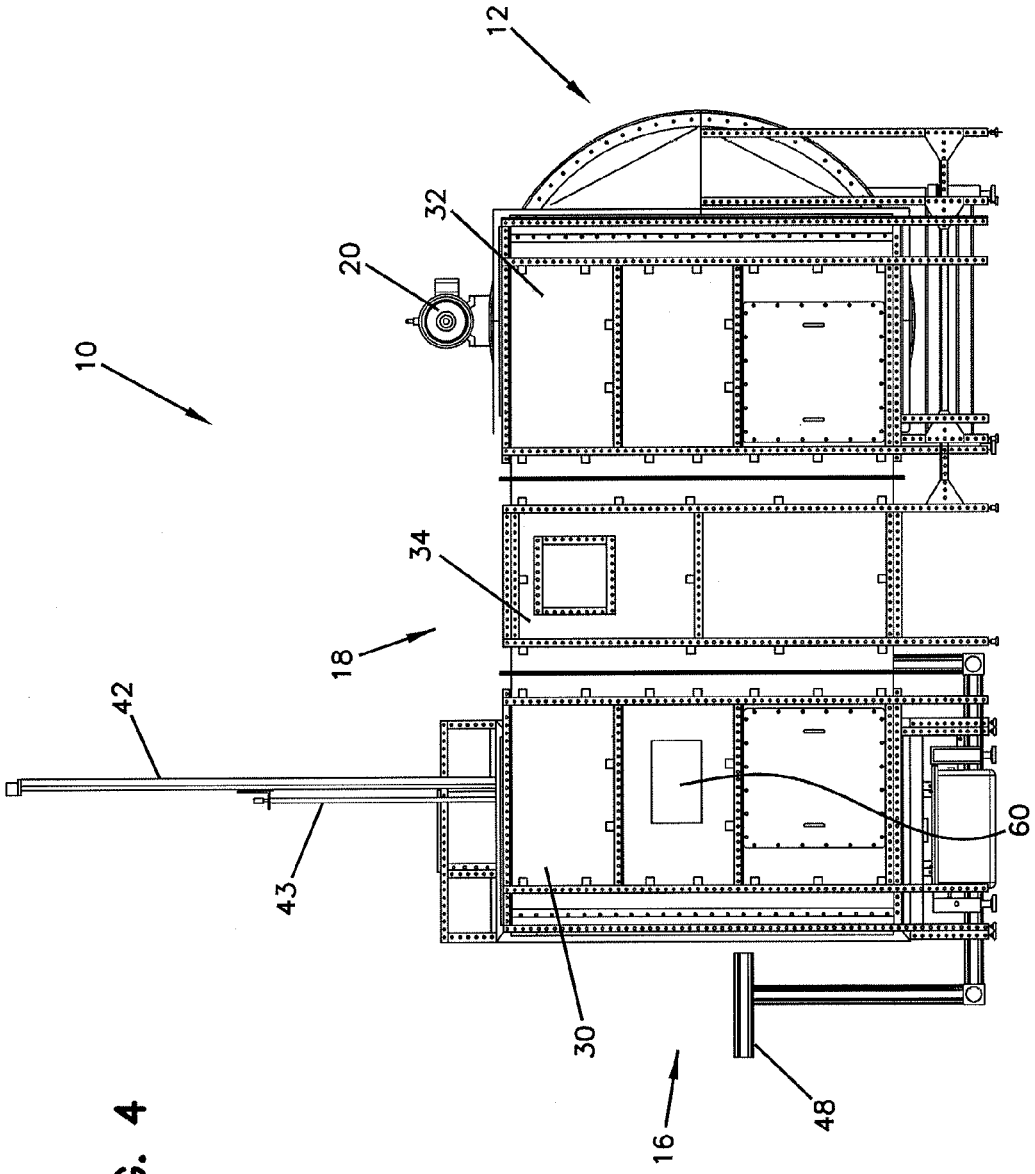

FIG. 4

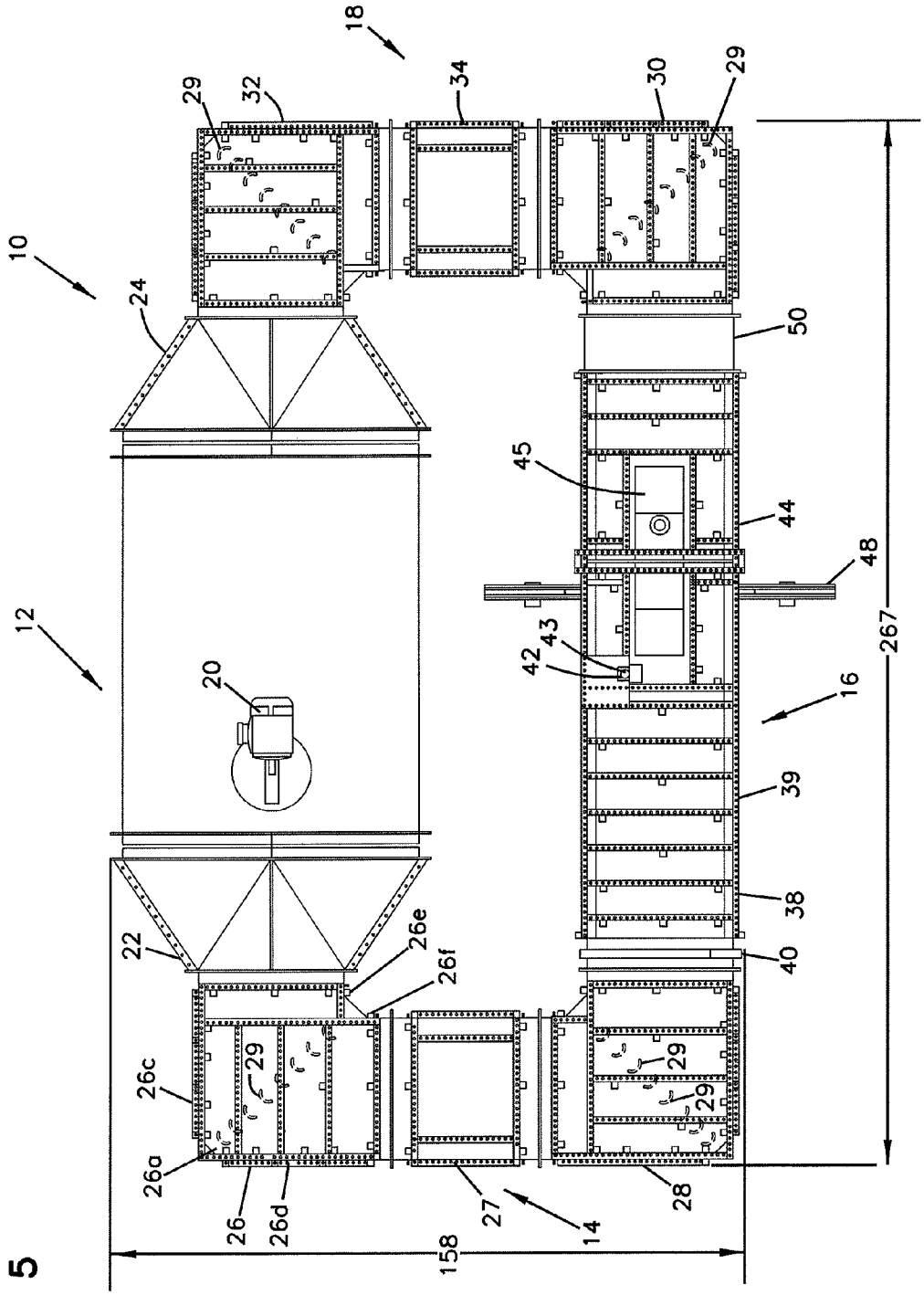
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FIG. 5

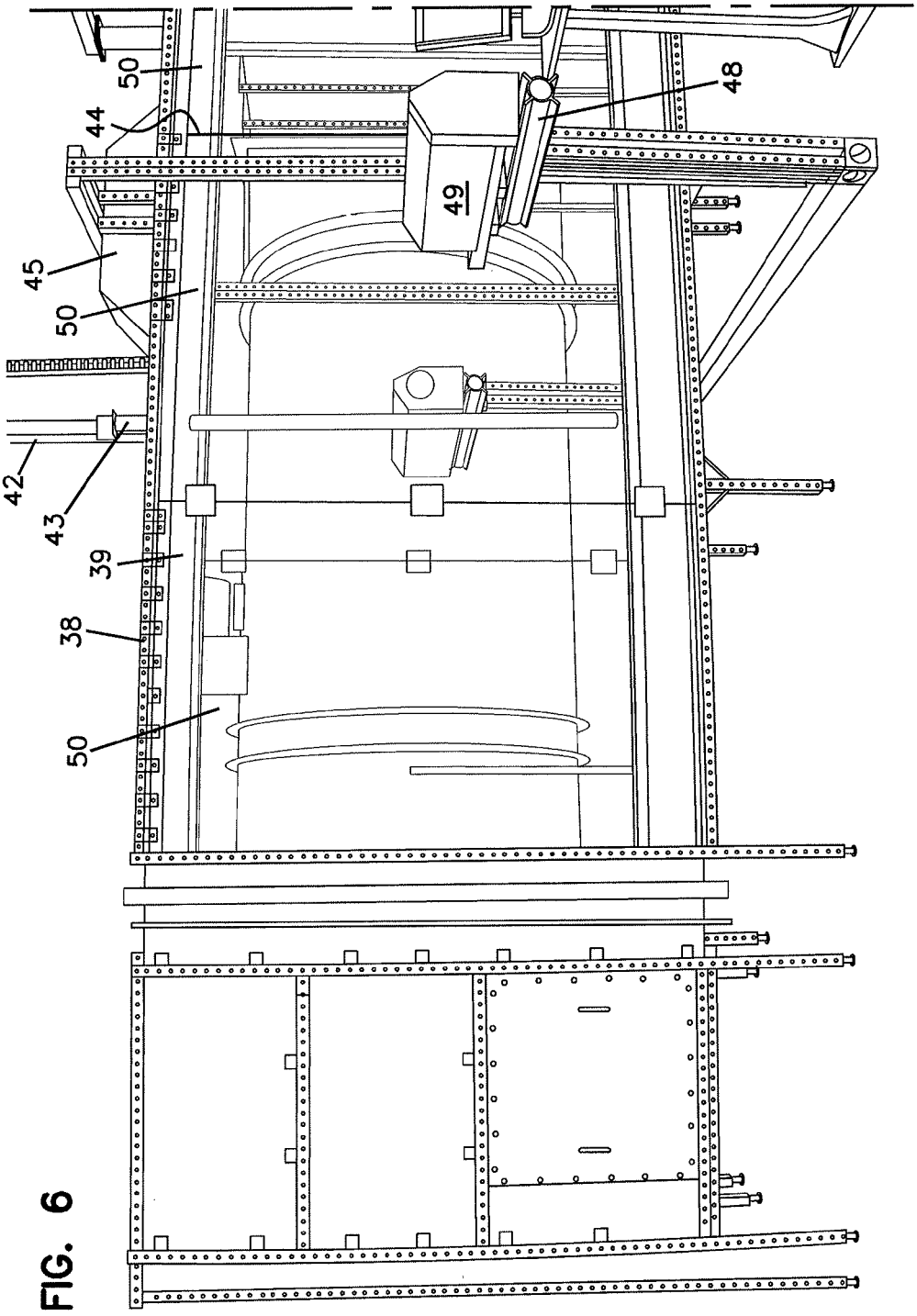

FIG. 6

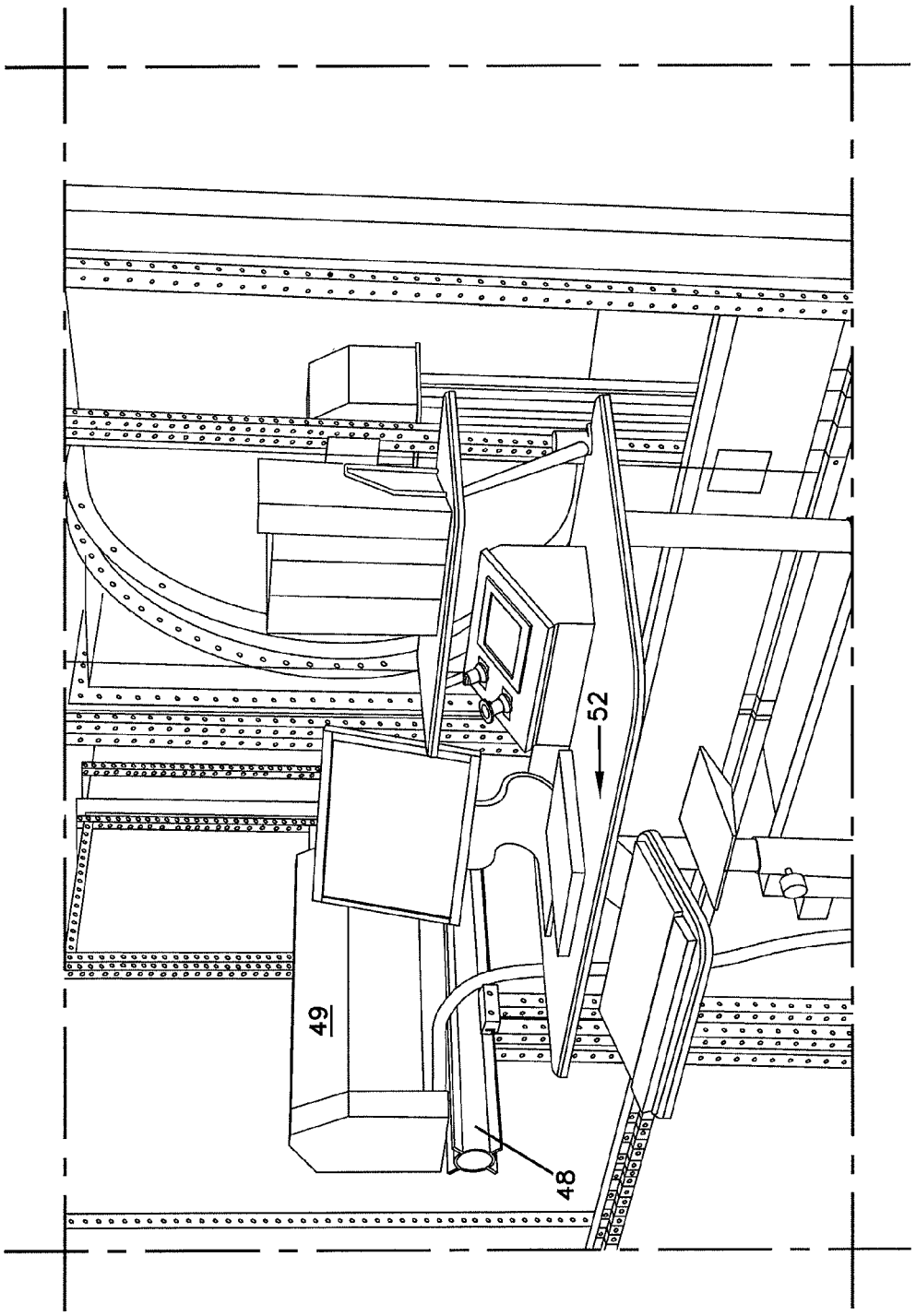

FIG. 7

LOW SPEED WIND TUNNEL DESIGN FOR AGRICULTURAL SPRAY PARTICLE ANALYSIS

CROSS-REFERENCED RELATED APPLICATIONS

This application is a continuation of U.S. patent application Ser. No. 13/614,522 filed on Sep. 13, 2012, issued as U.S. Pat. No. 8,689,619 on Apr. 4, 2014, which claims priority to U.S. Provisional Application No. 61/588,058 filed on Jan. 18, 2012, the entire contents of which are incorporated herein by reference.

FIELD OF THE INVENTION

This application relates to wind tunnel devices for agricultural spray analysis, and more particularly to wind tunnel devices configured as substantially closed systems that reduce exposure to agricultural sprays during analysis while providing for the aerodynamic flow of air and spray particulates.

BACKGROUND

Due to increasing concern about pest control costs and environmental pollution associated with agricultural sprays, application of such sprays requires precision and care. Considerable research on spray drift has been conducted, but it remains a major problem associated with many agricultural spray applications.

Field tests provide some information on factors influencing spray drift. However, field tests are limited by weather conditions that cannot be controlled and often vary during a test. Due to non-controlled environment, assessing the influence of some variables on spray drift is difficult. Consequently, laboratory tests are used to evaluate drift associated with spray deposits discharged from spray tips at various wind velocities in wind tunnels. However, wind tunnels are generally costly and may expose the tester to the agricultural spray, which can have negative health effects on the tester.

The US EPA will soon implement a new Drift Reduction Technology (DRT) program which would allow farmers and applicators to reduce the size of buffer zones required on some herbicide labels. DRT will need to be certified through the use of spray particle analysis or field trials proving a reduction in fine droplets subject to off-target drift. As a result, more frequent use of wind tunnels may be required for certification.

SUMMARY

In view of the foregoing, there is a need to provide wind tunnel devices that are configured cost-effectively and that shield operators of the wind tunnel devices from exposure to potentially harmful agricultural sprays. Accordingly, wind tunnel devices provided herein are configured as substantially enclosed systems for transporting airflow through the system to carry agricultural spray droplets past an analyzer, capturing substantially all of the spray droplets, and re-circulating the airflow through the system. The closed systems may have a rectangular shape and may include devices for facilitating an aerodynamic flow of the air through the system as well as transparent sidewalls free of openings adjacent to the analyzer.

According to one implementation, a wind tunnel device includes a segmented enclosure configured with an enclosed interior defining a cyclical tunnel for receiving continuous airflow therein. An airflow system delivers airflow through the tunnel including a testing region therein. In the testing region, a first portion carries an arm including a spray tip configured to spray particulates in the testing region at an angle and a second portion includes an enlarged cutout region configured to receive the angled spray particulates. The second portion with the enlarged cutout region accommodates the area covered by the angled spray particulates. The airflow carries the angled spray particulates from the spray tip into the enlarged cutout region such that the angled spray particulates pass through and exit the second portion of the testing region. As the airflow exits the testing region, it returns to the airflow system through the enclosed interior defining of the cyclical tunnel thereby re-circulating the airflow.

According to another implementation, a method of analyzing spray particulates in a wind tunnel involves providing a segmented enclosure configured with an enclosed interior defining a cyclical tunnel for receiving continuous airflow therein; providing an airflow system and a testing region within the segmented enclosure such that the airflow system delivers airflow through the cyclical tunnel including the testing region; providing the testing region with a first portion carrying an arm including a spray tip configured to spray particulates in the testing region at an angle and providing the testing region with a second portion including an enlarged cutout region for accommodating the area covered by the angled spray particulates and a transparent sidewall free of openings. Angled spray particulates are sprayed from the spray tip and are analyzed through the transparent sidewall free of openings. The airflow carries the angled spray particulates from the spray tip into the enlarged cutout region such that the spray particulates pass through and exit the second portion of the testing region. The airflow is re-circulated through the enclosed interior defining the cyclical tunnel as the airflow exits the testing region.

In yet a further implementation, a wind tunnel includes a fan, a first section, and second section, and a third section connected to form a generally rectangular shape, wherein the fan, the first section, the second section, and the third section form a tunnel that allows for the passage of air. A traversing arm is attached to the second section and adapted to receive a spray tip and to telescope and extend the spray tip into the volume defined by the second section. A first expansion cutout is attached the second section and forming a portion of a ceiling of the second section. A second expansion cutout is attached to the second portion and forming a portion of a floor of the second section. An angle of expansion of the first and second expansion cutouts enables spray particles from the spray tip to pass through and exit the second section.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** shows a perspective view of one embodiment of a wind tunnel device according to certain implementations.

FIG. **2** shows a left side view of the wind tunnel device of FIG. **1**.

FIG. **3** is a front view of the wind tunnel device of FIG. **1**.

FIG. **4** is a right side view of the wind tunnel device of FIG. **1**.

FIG. **5** is a top plan view of the wind tunnel device of FIG. **1**.

FIG. **6** is a front left side view of the wind tunnel device of FIG. **1**.

FIG. **7** is a view of an operating console that may be provided in connection with the wind tunnel device of FIG. **1**.

DETAILED DESCRIPTION

Research has shown that the most reliable data for spray particle analysis comes from using a wind tunnel to move fine spray particles away from an analysis device to prevent duplicate measurements. This disclosure relates, in part, to low speed wind tunnels used for analysis of spray particle size.

Wind tunnel devices provided herein may provide for accurate laser analysis of spray particles, which may be used for: product development (such as spray tip development); formulation development (such as active ingredients, e.g., herbicides, and adjuvants, e.g., drift reducer compositions); product label development; drift reduction technology development (e.g., spray tips, active ingredients and adjuvants); and grower and applicator training and education. Wind tunnel devices may accordingly be configured to test a variety of herbicide active ingredients, adjuvants, spray tips, and combinations of these to evaluate potential off-target movement.

FIG. **1** shows a perspective view of one embodiment of a wind tunnel device **10** according to certain implementations. The wind tunnel device **10** may include a series of segments or sections. Each of the sections may include a first end and a second end, such as a ceiling and a floor, respectively, as well as sidewalls therebetween. The sections may be generally rectangularly shaped and open at two sides to enable the sections to be interconnected. Some of the sections may be configured as corners and may include two open sides arranged at a right angle. For example, as shown in FIG. **1**, the wind tunnel device **10** may include a fan **12**, a first section **14**, a second section **16**, and a third section **18**. The fan **12** and the three sections **14**, **16**, **18** may form a generally rectangular footprint for containing the airflow. A tunnel **19** may be defined within the volume enclosed within an interior defined by the fan **12** and the three sections **14**, **16**, and **18** of the wind tunnel device **10** and may enable airflow to pass therethrough. The tunnel **19** may be cyclical such that a volume of airflow moves from the fan **12** sequentially into the sections **14**, **16**, **18**, and from section **18**, the airflow may re-circulate back into the fan **12** without allowing the passage of particulates or airflow to the exterior of the device. Providing a cyclical circuit enables the airflow to be reused, which reduces the amount of air exiting the wind tunnel device **10** and minimizes particulate exposure. In some implementations, seals may be provided between the sections to further minimize the possibility that particulates or circulating airflow will be transported outside the wind tunnel device **10**.

The fan **12** of the wind tunnel device **10** may include a motor **20** configured to drive the fan **12**, which may be communicatively coupled to a control system or an operating console of the wind tunnel device **10** (see FIG. **8**). In a particular embodiment, the fan **12** is manufactured by Twin City Fan M/N (TSL SW Model 542), and is of the inline centrifugal type. As shown in FIGS. **1** and **5**, the fan **12** may be joined to the first section **14** by a first duct **22** and to the third section **18** by a second duct **24**. In one embodiment, the motor **20** is a 7.5 horsepower motor that may be configured to generate wind speeds of between about 1 and 20 miles per hour at a spray tip **25** (described below), or between about 1 and 14 miles per hour. Those skilled in the art will appreciate that a wide variety of commercially available fans with horsepower requirements ranging from 5 horsepower to 30 horsepower, or at about 5, 7.5, 10, 15, 20, 25, 30 horsepower may be used in connection with the wind tunnel device **10**. Typically, the wind speed in the other portions of the flow circuit defined by the wind tunnel device **10** is equal to that of the test section, which is described further below in connection with the second section **12**. However, in some implementations, flow may be expanded through a portion of the flow circuit and may be contracted through a duct or other air flow control device upstream from the test section.

The first section **14** of the wind tunnel device **10** may include a first corner **26**, a first middle section **27** and second corner **28**. As shown in FIGS. **1**, **2** and **5**, the first corner **26** may be joined to the second corner **28** by way of the first middle section **27** and may form one side of the generally rectangular shape of the wind tunnel device **10**. A portion of the tunnel **19** is formed within the volume enclosed by the first section **14**. As shown in FIGS. **1**, **2**, **3** and **5**, each corner **26**, **28** is generally rectangular, may define a generally rectangular cross-section and may define openings at right angles relative to one another. As shown in FIG. **5**, two adjacent sides of a corner **26**, **28** form a generally right angled surface at the exterior of the wind tunnel device **10**. In order to limit wind resistance due to such angles, each of the first and second corners **26** and **28** may include turning vanes **29** within an interior of the corners **26**, **28**. The turning vanes **29** may be configured as vertically extending members joined to top ends **26***a*, **28***a* and bottom ends **26***b*, **28***b* of the first and second corners **26** and **28**, respectively. In some implementations, the turning vanes **29** may be configured as louvers or aerodynamic arcuately shaped vanes. In more specific implementations, the turning vanes **29** may be constant-arc vanes (e.g., high efficiency profile (HEP) turning vanes manufactured by Aerodyne). Other turning vane geometries may include, but are not limited to, single thickness circular arc designs, multiple thickness circular arc designs, single thickness airfoil designs, and multiple thickness airfoil designs. In some implementations, the turning vanes **29** may be spaced intermittently along a diagonal line from the interior of the corner to the exterior of the corner **26**, for example, extending between internal intersection points where the outside exterior walls **26***c*, **26***d* meet and at which internal exterior walls **26***e*, **26***f* meet. The turning vanes **29** may be configured to provide minimum loss and disturbance of air flow as the air turns the corner channels. That is, the turning vanes **29** may be placed at generally right angled surfaces within the corners **26**, **28** to reduce wind resistance and direct airflow away from the right angled surfaces and some turning vanes **29** may be spaced apart within the corner **26**, **28** to more evenly direct the airflow. In some implementations, airflow may be turned within the wind tunnel device without any turning vanes.

As shown in FIGS. **1**, **3**, **5** and **6**, the second section **16** of the wind tunnel device **10** may be configured as a generally rectangular cabinet and may define the test section **38**. The test section **38** may join to the second corner **28** of the first section **14** and to a first corner **30** of the third section **18**. A portion of the tunnel **19** is formed within the volume enclosed by the test section **38**.

The test section **38** of the second section **16** may generally define another side of the rectangular shape of the wind tunnel device **10**. The rectangular test section **38** may be configured to include a first portion **39** with a honeycomb air stabilizer unit **40** (not shown), a traversing arm housing **42** with a traversing arm **43** holding the spray tip **25** (FIG. **6**), a second portion **44** with a first expansion cutout **45**, a second expansion cutout **46**, a laser mount **48** that may hold a laser **49**, glass wall sections **50** and a spray particle scrubber **51**. The test section **38** may have an area that is 6 feet high by 3 feet wide by 12 feet long. In some implementations, the test section **38**

may have various dimensions, and preferably the test section includes a length of at least 36 inches, and a width and a height that are at least one meter.

The first portion **39** of the test section **38** may be configured to accommodate movement of the traversing arm **43**, described below. In addition, the first portion **39** may generally define a rectangular cross section with a ceiling at the upper end **38***a* of the test section **38**, a floor at the lower end **38***b* of the test section **38**, and a pair of opposing sidewalls arranged therebetween. In some implementations, glass wall sections **50** may be provided as the sidewalls of the first portion **39**.

The honeycomb stabilizer unit **40** may generally be placed at the entrance to the test section **38**. For example, the honeycomb stabilizer unit **40** may generally be positioned at the interface where the second corner **28** of the first portion **14** joins to the rectangular test section **38**. The unit may include a honeycomb structure that allows air to pass through the structure, and may facilitate a more uniform and straight air flow from the second corner **28** into the test section **38**. In one embodiment, the air stabilizer unit, or flow conditioner, may ensure both straightness and uniformity of the airflow as it passes the spray tip. The honeycomb stabilizer unit **40** may have a size and shape similar or the same as a cross-section of the wind tunnel, and may include a honeycomb structure with cells of various configurations. For example, a series of hexagonally-configured cells may each have dimensions of about 2 inches by about 0.25 inches. In addition to the hexagonal cell geometry, the cells may have square and round geometries, and may include cells sizes adapted for flow conditioning that may include a thicknesses likely ranging between 1" up to 4"×¼", ⅜", ½", ¾" and 1". Materials that may be used to fabricate the cells may include, but are not limited to, aluminum, polycarbonate, PVC, ABS, polypropylene, stainless steel, and titanium.

The traversing arm housing **42** may be joined at the first portion **39** at a first end **38***a* of the test section **38**, as shown in FIGS. **1** and **3**. The traversing arm housing **42** may be configured to guide the traversing arm **43** into the space defined by the first portion **39** of the test section **38**. In some implementations, the traversing arm housing **42** may include a track for guiding the traversing arm **43** and a seal arranged at an opening where the traversing arm **43** enters the test section **38**. The seal between the housing **42** and the traversing arm **43** ensures spray particulates do not escape the test section during spraying and testing.

The traversing arm **43** may extend from the traversing arm housing **42** and may receive the spray tip **25**. In some implementations, the spray tip **25** is offset from the traversing arm **43**, for example by about 6 to 8 inches. In this example, the spray tip **25** may be coupled to the traversing arm **43** via a conduit such as a rigid conduit projecting horizontally from the traversing arm **43** and fluidly coupled to the spray tip **25**. In further implementations, the traversing arm **43** or the conduit is adapted for the interchangeable attachment of spray tips and may include a supply line coupled to a fluid delivery system for delivering fluid to the one or more spray tips joined thereto. The spray tip **25** may be configured to emit a spray forming spray particulates, and the spray tip **25** may be selected from a variety of spray tips (e.g., nozzles) such as those used in agricultural applications.

The traversing arm **43** may be controllably lowered and raised between the first end **38***a* of the test section **38**, which may be proximate a ceiling of the first portion **39** of the test section **38**, and a second end **38***b* of the test section **38**, which may be proximate a floor of the first portion **39**. This movement may be through the use of a stepper motor (not shown), which moves the traversing arm **43** along the traversing arm housing **42**.

In some implementations, the traversing arm **43** may be shaped similar to an airplane wing as shown in FIG. **6**. For example, an airfoil shaped traversing arm **43** produced by Carlson Aircraft. Some suitable airfoil shapes for the arm **43** may be symmetrical circular arc shapes, symmetrical polynomial generated shapes, symmetrical matched ellipse shapes, and symmetrical NACA (National Advisory Committee for Aeronautics) airfoil shapes. The airfoil shape of the traversing arm **43** may provide less disruption to the air flow within the test section **38**. However, other shapes may also be used for the traversing arm **43**. In further implementations, the traversing arm housing **42** and traversing arm **43** may be fully enclosed within the test section **38**. In this implementation, the traversing arm **43** may move along the traversing arm housing **42** within the test section **38**, which may further minimize the possibility that particulates from the spray tip **25** will be transported outside the wind tunnel device **10**.

The second portion **44** of the test section **38** may be configured as a fully enclosed testing region of the test section **38** where the spray particulates are analyzed. The second portion **44** includes a first expansion cutout **45** and a second expansion cutout **46** protruding outwardly from the first and second ends **38***a*, **38***b* of the test section **38** proximate a floor and a ceiling of the test section **38**, respectively. The second portion **44** of the test section **38** with the expansion cutouts **45**, **46** accordingly defines a space with cutouts forming an angled ceiling and an angled floor separated by sidewalls. The sidewalls of the second portion **44** may include the glass wall sections **50** in an area proximate where the spray analysis is conducted, described below. The configuration of the second portion **44** of the test section **38** accommodates the spray angles provided by the spray tip **25** joined to the traversing arm **43**. In contrast, the space defined by the first portion **39** of the test section **38** may be unable to accommodate the spray angles provided by the spray tips **25** due to height limitations. For example, because the first portion **39** of the test section **38** is configured to allow the traversing arm **43** to translate between the first and second ends **38***a*, **38***b* of the test section **38**, angled spray emitted from the spray tip **25** may otherwise contact the first and second ends **38***a*, **38***b* of the cabinet **30**, e.g., the first portion **39** may define an area that is smaller than an area covered by the angled spray particulates. The expansion cutouts **45**, **46** downstream from the spray tips **25** are configured to minimize such contact by the spray particulates.

The expansion cutouts **45**, **46** may be configured as a five wall expansion piece with an opening for positioning over an opening in an upper or lower end **38***a*, **38***b* of the test section **38**. Walls of the expansion cutouts **45**, **46** include angled sides that define an expansion angle **52** that is approximately equal to the widest spray angle emitted by the spray tip **25** used in connection with the traversing atm **43**. In some implementations the spray tip **25** may deliver a maximum spray angle of 140° and the expansion cutouts **45**, **46** may be configured to accommodate this or other maximum spray angles. In some implementations, the expansion angle for the cutout may be about 45°. However, the expansion angle may vary from about 10° to about 90°. The depth of the expansion cutouts may be about 12 inches, and the size of the rectangles cut into the test section wall for receiving the expansion cutout may be about 12 wide by about 48 inches long. In some implementations, the cutouts **45**, **46** may be configured with the same shape. The first expansion cutout **45** may include a drip tray that prevents any spray that impinges on the test section walls from dripping through the measurement area. The second

expansion cutout **46** may include a drain for draining the collected liquid. In some implementations, the first expansion cutout **45** may define a small opening that may generally be capped, which may allow for a suction system to condition the flow past the first expansion cutout **45**, for example.

The expansion cutouts **45** and **46** in combination with the second portion **44** of the test section **38** may be configured to allow the spray from wide and narrow angle spray tips **25** to be analyzed within the second portion **44** of the test section **38** without the spray bouncing off or collecting and dripping from the ceiling and the floor of the test section **38**. For example, as a wide angle spray tip **25** is spraying a fluid (e.g., a herbicide) when it is at the top end **38***a* of the test section **38**, the spray pattern of the herbicide may follow one or both of the angled expansion cutouts **45**, **46** and the spray pattern may be allowed to flow along the expansion cutouts **45**, **46** and the second portion **44** so that the spray pattern may be analyzed by the laser **48** and the particulates may exit the second portion **44**. For example, the configuration of the expansion cutout **45** may prevent some droplets from forming on the ceiling of the first end **38***a* of the test section **38** above the space covered by the laser **49** by allowing the droplets to pass into and out of the expansion cutout **45**. Similarly, the expansion cutout **46** may be configured at an angle at the second end **38***b* of the test section **38** to prevent splatter from the herbicide hitting the floor of the second end **38***b* of the test section **38** and enter the space covered by the laser **49** by allowing the droplets to pass into and out of the expansion cutout **46**. The expansion cutouts **45**, **46** may thus be configured to limit measurement errors due to errant drops (e.g., droplets that drip down from walls or bounce off of walls) passing through the laser path such as preventing fluid drops from forming as a result of hitting the ceiling or floor of the top and bottom ends **38***a*, **38***b* of the test section **38** and entering the space covered by the laser **49**. Further, while some particulates may contact the drip tray of the first expansion cutout **45**, the drip tray may prevent drop formation and channel the particulates downstream from the testing region thereby preventing such drops from falling in the space covered by the laser. Other particulates contacting the second expansion cutout **46** may be collected and drained.

The laser mount **48** of the test section **38** may be positioned proximate the second portion **44** of the test section **38** and may be configured to receive a laser **49** or other analysis devices. The laser mount **48** may be movable horizontally and/or vertically at least along the glass sections **50** of the second portion **44** to enable the laser **49** to measure spray particulates from various types of spray tips. For example, some spray tips **25** may deliver a sheet of liquid from an orifice and the sheet may break apart into spray particulates at a certain distance away from the orifice of the spray tips **25**. In this example, the laser mount **48** and the laser **49** may be moved horizontally to a position along the second portion **44** corresponding to a location downstream from the nozzle where the spray particulates form. In some implementations, the laser mount **48** may translate horizontally from 0 to 24 inches from the spray tip, 2 to 18 inches from the spray tip or any combination thereof. In some implementations, the laser mount **48** may translate vertically while the spray tips remain stationary. While the analysis device described herein is a laser, it will be appreciated that other analysis devices may be used such as video imaging.

The glass sections **50** of the test section **38** may be configured to enable analysis, such as laser analysis, of the spray particulates without forming openings within the sidewalls of the test section **38**. The glass used in the wind tunnel device **10** may be a ⅜" nominal thickness, low-iron, annealed, soda-lime glass. Acceptable glass configurations for the test section may include, but are not limited to, ¼" nominal thickness, ⅜" nominal thickness, and ¾" nominal thickness, and substantially equivalent metric sized materials. Acceptable compositions for the glass may include, but are not limited to, soda-lime, low-iron soda lime, and borosilicate. In some implementations, fused quartz and sapphire may be used in areas to where the laser analysis takes place. Low iron glass may be preferred due to its increased optical transmission. In addition, available tempers are annealed, strengthened, and tempered, but annealed glass is preferable due to its low optical distortion for the laser. Some installations may use tempered glass, for example, as a safety precaution. By analyzing the spray particulates within an environment separate from the user and from the analysis device, analysis may be performed by the user without risking exposure to potentially harmful chemicals and the analysis device remains free of spray particulates, which may facilitate avoiding inaccurate measurements. While providing glass sections **50** along sidewalls of the second portion **44** of the test section **38** is preferred, other areas of the test section **38** may also include glass sections. For example, as shown in FIG. **6**, the first portion **39** of the test section **38** may include sidewalls formed of glass sections **50** such as optical glass walls configured to enable the user to view movement of the traversing arm **43**. In some implementations, the glass sections **50** may be hinged to allow access to the interior of the test section **38**, for example, to allow attachment of spray tips **25** and maintenance.

A spray particle scrubber **51** of the test section **38** may be joined between the second portion **44** of the test section **38** and the third corner **30** of the third section **18**. In some implementations, the spray particle scrubber **51** may be configured to collect the droplets exiting the second portion **44** of the test section **38** and may prevent the droplets from continuing through the tunnel **19** defined by the wind tunnel device **10**. With the use of a spray particle scrubber **51**, the air may be reused and provided to the fan **12**, for example. In one embodiment, the scrubber **51** may be configured as a mist extractor. In another embodiment, the scrubber **51** may be 99.7% effective at removing particles greater than 5 μm diameter. For example, the spray particle scrubber **51** may use a series of angled channels to change the flow path of the particles, allowing them to settle out and run down the channels, into the waste disposal unit.

As shown in FIG. **7**, a computer **52** may be configured as an operating console for the wind tunnel device **10** and may be communicatively coupled thereto. The computer **52** may include a processor, a memory and a network connection. In some implementations, the computer **52** may be used to operate the traversing arm **43**, the laser mount **48**, the laser **49**, a fluid delivery system for delivering fluid to the spray tips **25** and so on. For example, using the computer **52**, an operator may adjust the position of the laser mount **48** and the laser **49** horizontally and vertically. This may protect the laser **49** from being handled while readjusting and repositioning the laser **49**. In some implementations, the laser **49** may be operated using proprietary Sympatec software, WINDOX provided on the computer **52**. In addition, the computer **52** may be configured to control the traversing arm **43** to lower and raise the spray tip **25** joined thereto. A traversing arm motor (not shown) may also be operated using software on the computer **52**.

As shown in FIGS. **1** and **4**, a control box **60** is mounted to the exterior of the wind tunnel device **10** and may be used to control the wind speed and a waste pump (not shown). The control box **60** may be operated using the computer **52** or may be operated separately therefrom.

As shown in FIGS. **1**, **4** and **5**, the third section **18** of the wind tunnel device **10** may include a third corner **30** and a fourth corner **32** connected by a second middle section **34**. As shown in FIG. **5**, the third corner **30**, the fourth corner **32**, and the second middle section **36** may define another side of the generally rectangular shape of the wind tunnel device **10**. A portion of the tunnel **19** is formed within the volume enclosed by the third section **18**. Similar to the first and second corners, each of the third and fourth corners **30** and **32** may include turning vanes **29**. The third section **18** provides a connection between the fan **12** and the second section **16** to enable airflow to be re-circulated within the wind tunnel device **10**. In some implementations, an exhaust system may be joined to the third section **18** to provide for safe removal of vapors or other contents in the airflow prior to re-circulating the airflow to the fan **12**.

The wind tunnel device **10** disclosed herein provides several advantages over prior approaches. Because the device **10** is configured to re-circulate airflow, ambient air (e.g., air from an external environment in varying climates) need not be pumped into the device **10** from external sources, or at least a reduced amount of air is pumped into the device. For example, during summer and winter months when ambient temperatures are warm or cold, air within the device **10** may be reused, which avoid cooling and heating airflow prior to its introduction into the device **10**. A further advantage provided by the device **10** is the ability to provide the laser in a separate environment from the interior of the device. This prevents the laser from fouling from spray particulates. In addition, because the laser may be mounted to the laser mount **48**, the laser may be moved to multiple positions, which is in contrast to prior approaches in which lasers were statically mounted within a chemical hood. Yet another advantage provided by the device **10** is the ability to move the spray tip **25** within the device, including use of wide angle spray tips (110 to 140°) without fouling the test section. This differs from prior approaches in which the spray tip is mounted in one position, which may be problematic for leveling. Another advantage of the device is that the fully enclosed test chamber, facilitated by the optically clear glass, allows safe testing of active pesticide products.

Implementation of Use

In one implementation of use, the fan **12** may be operated by the motor **20** to force air through the tunnel **19** defined by the wind tunnel device **10**. A spray tip **25** is attached to the traversing arm **43** of the test section **38**. A conduit system adapted to transport fluids delivers fluid to the spray tip **25** to be sprayed therethrough. In some implementations, fluid may be forced to travel through the conduit system using an air compressor, pumps and so on. For example, the fluid to be delivered to the spray tip **25** may be tank mixed and pressurized within the tank, the conduit system or both. The conduit system may be coupled to a flow meter in order to measure the flow rate and pressure of the fluid passing therethrough prior to exiting the spray tip **25**. In general, the spray tip **25** configuration determines the flow rate and the pressure of the exiting spray. The use of a flow meter provides confirmation that the fluid passing through the conduit system is moving properly, or so that any pressure drops may be accounted for when analyzing the spray exiting the spray tip **25**. This enables the user to comply with ASAE/ANSI S572.1 test standard for quality control and size classification of agricultural nozzles, which may vary in quality when purchased from the manufacturer.

Using a computer **52**, the traversing arm **43** is vertically lowered and raised within the first portion **39** of the test section **38** so that that spray tip **25** travels from the first end **38***a* of the test section **38** to the second end **38***b* of the test section **38**. A fluid, such as an herbicide, is sprayed and the airflow passes the spray tip **25** at between 1 and 14 miles per hour. The spray tip **25** delivers spray at about a 110° spray angle, which may exit the spray tip in a vertical orientation. However, the spray angle delivered may exceed 140°, for example, depending on the spray tip and fluid sprayed therefrom.

The airflow carries spray particulates from the spray tip **25** into the second portion **44** of the test section **38** with the first and second expansion cutouts **45**, **46**. The expansion cutouts **45**, **46** of the second portion **44** may substantially prevent droplets from forming on the ceiling above the space covered by the laser **49**, and the expansion cutout **46** prevents droplets from bouncing off the floor and into the space covered by the laser **49**. In some cases, the spray area may be larger than the second portion **44** of the test section **38** with the first and second expansion cutouts **45**, **46**, and may impinge upon the test section floor and ceiling but the particulates may be collected in a drip pan and channeled away from the test section. Prior to measurement of the spray particulates, the computer **52** is used to position the laser **49**. The computer **52** is used to collect readings and determine particle size, which may then be analyzed. In some embodiments, the analysis may be used to classify the spray particle size as "Very Fine," "Fine," "Medium," "Coarse," and "Very Coarse."

The spray particulate measurements primarily may be taken while traversing the arm vertically up or down. Generally, for full-pattern analysis, the spray pattern measured during the run must clear the laser measurement area, prior to and after the run. The laser analysis may be triggered by the spray entering the test area and stopped when the spray exits the test area.

The spray can also be measured from a static position in a variety of orientations for other types of analysis. The wind tunnel device **100** provided herein is particularly useful for identifying spray particulates of various sizes, including particulates having a size limit of less than 150 μm and less than 105 μm.

The wind tunnel device **10** provided herein, with the laser mount **48** proximate the glass sections **50** of the second portion **44**, along with the expansion cutouts **45**, **46**, may enable the device **10** to deliver airflow past the spray tip **25** at a speed of between about 1 and 14 miles per hour, which corresponds to low testing speeds. Using low testing speeds, the laser **49** may accurately detect the particle sizes of the spray particulates within the testing region.

In addition, the results of the laser **49** analysis may provide accurate results because the expansion cutouts **45**, **46** may prevent errant drops from passing through the path of the laser, described above.

Providing glass sections **50** proximate the laser mount **48** enables the laser **49** to analyze the spray particulates without the particulates contacting the laser **49**. Users of the wind tunnel device **10** are also protected from exposure to the spray particulates due to the enclosed space formed by the series of joined segments forming the wind tunnel device **10**.

The cyclical or rectangular shape of the wind tunnel device **10** further provides a system that re-circulates airflow, as described above. The re-circulated airflow entering the fan **12** may be clean using the spray particle scrubber **51** positioned downstream from the testing region **44** and upstream from the fan **12**.

The following Example Embodiment provides an implementation in which the wind tunnel device **10** is used to

analyze spray particulates from various spray tips; however, this Example Embodiment should not be construed as limiting.

Example Embodiment

In a particular embodiment, a wind tunnel device designed as low speed wind tunnel provided wind speeds from 1 to 14 miles per hour at the spray tip and included a laser analyzer, i.e., a Sympatec Helos Vario-KR laser diffraction particle size analyzer with an R7 lens, mounted on an automated adjustable base that moved the laser from 0-18 inches from the spray tip. The wind tunnel device was a cyclical closed system with a downstream spray mist extractor removing 99.7% of all spray particles down stream of the test section. The area used for spray particle measurements was 6 feet high by 3 feet wide with upper and lower expansion areas that allow for traversing of up to 140° angle spray tips. The study observed the percentage of droplets within a size limit of less than 150 μm and less than 105 μm. Droplets sized below these thresholds are generally undesirable in spray applications due to their potential to contribute to spray drift.

In this example, two spray tips were analyzed and a drift reducer was also analyzed using the spray tips. The tests were conducted with the spray tips traversed at the bottom of an aerodynamic arm joined to the cabinet of the wind tunnel device. The wind speed, spray pressure, traversing arm, and laser operation were controlled by a control panel operated by a user. The waste water was removed from under the extractor by an enclosed system. The water is pumped from the enclosed container into shuttles which are then shipped away for disposal.

The results of spray particulates produced by two different spray tips, spray tip **1** (XR11002) and spray tip **2** (AIXR11004) are provided in Table 1 below.

TABLE 1

Examples of Spray Particle Analysis Water Compared to Herbicide Formula Through Two Spray Tips @ 40 PSI

Treatment	% particles <105 μm	% particles <150 μm	Volume Median Diameter (VMD)*
Spray tip 1 (XR11002)			
Water	19.9	41.4	168.7
Glyphosate + AMS	22.8	46	158.4
Spray Tip 2 (AIXR11004)			
Water	1.3	3.8	494.4
Glyphosate + AMS	2.7	7.6	387.6

*VMD = Half of spray volume is smaller and half the spray volume is larger than this number

Table 1 illustrates the use of the wind tunnel device for testing the two different spray tips, which results in the detection of a large difference for the production of droplets smaller than 150 μm. Spray tip **1**, XR11002 (XR TeeJet Extended Range Flat Spray Tip), spraying water and Glyphosate+AMS resulted in over 40 percent of the droplets having a size of less than 150 μm and about 20 percent of the droplets having a size of less than 105 μm. Spray tip **2**, AIXR11004 (AIXR TeeJet Spray Tip), spraying water resulted in 3.8 percent of the droplets having a size of less than 150 μm and about 1.3 percent of the droplets having a size of less than 105 μm. For the same spray tip, spraying Glyphosate+AMS resulted in 7.6 percent of the droplets having a size less than 150 μm and 2.7 percent of the droplets having a size of less than 105 μm.

The results of herbicide spray particulates produced without and with a drift reducer (AG2013) using two different spray tip's, spray tip **1** (XR11002) and spray tip **2** (AIXR11004) are provided in Table 2 below.

TABLE 2

Examples of Drift Reduction Adjuvant Reducing % of Fines in a Spray Mixture

Treatment	% particulates <105 μm	% particulates <150 μm	Volume Median Diameter (VMD)*
Spray tip 1 (XR11002)			
Glyphosate + AMS (control)	22.8	46	158.4
Glyphosate + AMS + AG02013	13.2	34	182.1
Spray Tip 2 (AIXR11004)			
Glyphosate + AMS (control)	2.7	7.6	387.6
Glyphosate + AMS + AG02013	0.7	2.8	459.4

*VMD = Half of spray volume is smaller and half the spray volume is larger than this number

Table 2 illustrates the use of the wind tunnel device for testing the control herbicide and the herbicide with the drift control agent (AG2013) results in the detection of a large reduction of herbicide drift using the control agent.

Although the present disclosure provides references to preferred embodiments, persons skilled in the art will recognize that changes may be made in form and detail without departing from the spirit and scope of the invention.

The invention claimed is:

1. A wind tunnel device comprising:

a segmented enclosure configured with an enclosed interior defining a cyclical tunnel for receiving continuous airflow therein, the segmented enclosure comprising an airflow system and a testing region, said airflow system configured to deliver airflow through the tunnel including the testing region, said testing region comprising:

a first portion carrying an arm adapted to receive a spray tip configured to spray particulates in the testing region; and

a second portion adapted to receive the spray particulates and accommodate the area covered by the spray particulates,

wherein the airflow carries the spray particulates into the testing region such that the spray particulates pass through and exit the second portion of the testing region, and

wherein the airflow exiting the testing region returns to the airflow system through the enclosed interior of cyclical tunnel thereby re-circulating the airflow.

2. The device of claim **1**, wherein the segmented enclosure further comprises a scrubber configured to collect the spray particulates exiting the testing region prior to re-circulating the airflow.

3. The device of claim **1**, wherein the airflow system comprises an air blower device configured to deliver the airflow to the testing region.

4. The device of claim **3**, wherein the segmented enclosure further comprises one or more vanes configured to direct the airflow from the air blower device to the testing region.

5. The device of claim 3, wherein the air blower device operates to deliver airflow past the arm at between about 1 and about 20 miles per hour.

6. The device of claim 1, wherein the testing region further comprises an airflow control device configured to control airflow past the arm such that the controlled airflow carries the spray particulates into the second portion of the testing region.

7. The device of claim 1, wherein the testing region comprises transparent sidewalls.

8. The device of claim 1, wherein the segmented enclosure comprises one or more seals.

9. The device of claim 1, wherein the arm is configured to interchangeably receive a plurality of individual spray tips configured to spray particulates.

10. The device of claim 1, wherein the arm is a traversing arm.

11. The device of claim 1, wherein the second portion of the testing region is adapted to accommodate spray particulates from different spray tips.

12. The device of claim 1, wherein the second portion of the testing region comprises transparent sidewalls, and wherein the wind tunnel further comprises an analyzer arranged at an exterior of the transparent sidewalls configured to analyze the spray particulates within an interior of the second portion of the testing region.

13. The device of claim 12, wherein the analyzer comprises a laser mounted on a laser mount adapted to adjust a position of the laser to a selected position along the second portion of the testing region.

14. The device of claim 1, wherein the second portion of the testing region comprises an enlarged cutout region adapted to accommodate an area covered by the spray particulates passing through and exiting the second portion of the testing region.

15. A method of analyzing spray particulates in a wind tunnel comprising:

providing a segmented enclosure configured with an enclosed interior defining a cyclical tunnel for receiving continuous airflow therein;

providing an airflow system and a testing region within the segmented enclosure such that the airflow system is adapted to deliver airflow through the cyclical tunnel including the testing region;

providing the testing region with a first portion carrying an arm adapted to receive a spray tip configured to spray particulates in the testing region;

providing the testing region with a second portion for accommodating the area covered by the spray particulates, the second portion comprising a transparent sidewall;

spraying the spray particulates from the spray tip;

analyzing, through the transparent sidewall, the spray particulates from the spray tip, wherein the airflow carries the spray particulates from the spray tip into, through and out of the second portion of the testing region; and

re-circulating the airflow through the enclosed interior defining the cyclical tunnel as the airflow exits the testing region.

16. The method of claim 15, further comprising traversing the arm within the first portion of the testing region from a first end of the first portion to a second end of the first portion opposite the first end during the analyzing.

17. The method of claim 15, wherein the analyzing is performed by a laser arranged at an exterior of transparent sidewalls of the second portion of the testing region.

18. The method of claim 17, further comprising adjusting the laser to a selected position along the second portion of the testing region prior to the analysis of the spray particulates.

19. The method of claim 15, further comprising providing a seal within the segmented enclosure.

20. A wind tunnel, comprising:

a first section, a second section, a third section and a fourth section connected to form a generally rectangular shape, wherein the first section, the second section, the third section and the fourth section form a wind tunnel that allows for the passage of air;

a traversing arm attached to the second section and adapted to receive a spray tip and to traverse into the volume defined by the second section;

a first expansion cutout attached to the second section and forming a portion of a ceiling of the second section; and

a second expansion cutout attached to the second portion and forming a portion of a floor of the second section,

wherein an angle of expansion of the first and second expansion cutouts enables spray particles from the spray tip to pass through and exit the second section.

21. The wind tunnel of claim 20, further comprising an analyzer mount and a computer processor adapted to adjust a position of the analyzer mount.

22. The wind tunnel of claim 20, wherein one of the sections comprises a fan.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 9,116,068 B2
APPLICATION NO. : 14/199531
DATED : August 25, 2015
INVENTOR(S) : Eric Spandl et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

TITLE PAGE ITEM (74) ATTORNEY, AGENT, OR FIRM:

PTO	Should Be
"Bridget M. Mayden"	-- Bridget M. Hayden --

SPECIFICATION:

Column	Line	PTO	Should Be
6	54	"the traversing atm 43."	-- the traversing arm 43. --
12	6	"spray tip's, spray tip 1"	-- spray tips, spray tip 1 --

Signed and Sealed this
Twenty-fourth Day of May, 2016

Michelle K. Lee

Michelle K. Lee
Director of the United States Patent and Trademark Office